Correlation Analysis for γ-ray and Broad Line Emissions of Fermi Blazars

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ABSTRACT

In a standard model of active galactic nuclei (AGNs), there is a supermassively central black hole surrounded by an accretion disk with the jet coming out perpendicularly to the disk plane. Theoretical works suggest that there is a connection between the jet and the accretion disk. To investigate such a connection, people use the correlation between the radio emission (or γ-ray emission) and the broad line emission. However, it is well known that the radio (or γ-ray) emission is strongly beamed in blazars. In this sense, we should consider the beaming effect when we discuss the jet–accretion disk connection.

In this work, we compiled a sample of 202 Fermi/LAT blazars with available broad line emissions. Out of the 202 sources, 66 have known Doppler factors. The correlation between γ-ray and broad-line emission, and that between radio and broad-line emission are investigated by removing the effects of redshift and beaming boosting for the whole sample and the subclasses, flat spectrum radio quasars (FSRQs) and BL Lacertae objects (BL Lacs) respectively. **We obtained a strong positive correlation between γ-ray and broad-line emission and between radio and broad-line emission for the 202 blazars; It's worth noting that the correlation still exists after removing redshift effect. For the 66 sources with Doppler factors, there is also a strong positive correlation between γ-rays and broad-line emission after removing the Doppler factors, as well as that between radio and broad-line emission.**

Our analysis suggest that 1. There are strong correlations between the γ-ray and the broad line emission for the whole blazar sample and their subclasses. The correlations exist when the redshift effect is removed for the whole sample and their subclasses, confirming the results by Ghisellini et al. (2014) and Chen (2018). 2. For the 66 blazars with available Doppler factors, a strong correlation between the broad line emission and the Doppler factor is found. The correlation between the γ-ray and the broad line emission exists after the Doppler factor effect is removed. **Similar results also obtained between radio and broad-line emission.** 3. Our analysis suggests a robust connection between the accretion process and the jet.

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1. introduction

Active galactic nuclei (AGNs) have some special observation properties, such as core-dominated non-thermal continuum, superluminal motions, high and variable luminosity, high and variable polarization, γ-ray emissions and so on (Fan et al. 2016, see also Lin et al. 2017; Lin & Fan 2018). Their properties are explained using a jet model with jet pointing close to the line of sight. As the most powerful subclass of AGNs, blazars can be divided into flat spectrum radio quasars (FSRQs) with strong emission lines and BL Lacertae objects (BL Lacs) with weak emission lines or no emission lines at all. From the Fermi detected blazars, Ghisellini & Tavecchio (2009) proposed that the BL Lacs and FSRQs can be separated in the plot of γ-ray photon index against the γ-ray luminosity (see also Abdo et al. 2009; Ackermann et al. 2015; Chen 2018). Ghisellini, et al. (2011) also pointed out that BL Lacs and FSRQs can be classified based on the luminosity of the broad line region ($L_{\rm BLR}$) measured in Eddington, and the dividing value is about $L_{\rm BLR}/L_{\rm Edd} \sim 5 \times 10^{-4}$, which was confirmed by Sbarrato et al. (2012, see also Yang et al. 2018a,b).

In the theoretical models of jet formation, a correlation between jet and accretion process is expected, the power converted into the kinetic power of jet is produced from a spinning black hole which can release its rotational energy (Blandford and Znajek 1977), or produced from accretion process and disc (Blandford and Payne 1982). In order to understand these relationships, a key way is to search for the connection between accretion process and jet, which has been studied in the literatures (Celotti et al. 1997; Cao and Jiang 1999; Sbarrato et al. 2012; Ghisellini et al. 2014; Xiong and Zhang 2014; Cao 2018; Chen 2018). The accretion disc produces radiation to ionize the surrounding clouds, and further to form the broad emission lines, so the accretion disc luminosity has a certain connection with the broad line region luminosity. In this case, we can use the broad line region luminosity ($L_{\rm BLR}$) to measure the accretion disc luminosity ($L_{\rm d}$), so $L_{\rm BLR}$ can be a proxy for the invisible accretion disk luminosity ($L_{\rm d}$) (Sbarrato et al. 2012).

For a sample of 159 steep-and flat-spectrum quasars, Serjeant et al. (1998) proposed that the radio luminosity ($L_{\rm R}$) is a good agent for the jet. On the other hand, the γ-ray luminosity (L_γ) can represent for bolometric luminosity since that the γ-ray luminosity dominates the bolometric luminosity in Fermi blazars. (Dondi & Ghisellini 1995; Fan, et al. 1999, 2017; Ghisellini et al. 2011; Sbarrato et al. 2012; Xie, et al. 2004), so the γ-ray luminosity (L_γ) is an agent for the jet.

Therefore, $L_{\rm BLR}$ is an proxy for accretion disc luminosity while $L_{\rm R}$ and L_γ are proxies for the jet. In order to explore the connection between jet and accretion radiation, a feasible way is to

explore the relationship between radio (or γ-ray) luminosity and broad-line luminosity. In 1999, Cao and Jiang collected a sample of 198 radio-loud quasars, estimated the total broad-line flux, and obtained a significant correlation between radio and broad-line emission. If the redshift is limited to the range $0.5 < z < 1.5$, a correlation with a significant level of 99.93% was obtained between the radio and broad-line fluxes, while a significant level of 99.7% was obtained between the radio and broad-line luminosities. One should note that the effect of the synchrotron self-absorption in blazars can lead to measured radio fluxes lower than the intrinsic radio fluxes, at least at lower frequencies, thus underestimating the radio luminosity. On the other hand, the γ-ray luminosity (L_γ) can represent for bolometric luminosity since that the γ-ray emissions dominate the bolometric luminosity in γ-ray loud blazars (Dondi & Ghisellini 1995; Ghisellini et al. 2011, 2014; Sbarrato et al. 2012), so the γ-ray luminosity (L_γ) is a good proxy for the jet.

Therefore, $L_{\rm BLR}$ is a proxy for accretion disc luminosity while L_γ is a proxy for the jet luminosity. In order to explore the connection between jet and accretion process, a feasible way is to explore the relationship between γ-ray luminosity and broad-line luminosity. Sbarrato et al. (2012) collected 78 blazars (with measured $L_{\rm BLR}$, L_γ and black hole mass) detected by the Fermi/LAT and presented in SDSS (Sloan Digital Sky Survey), searched the logarithmic relationship between the L_γ and $L_{\rm BLR}$, and found that $\log L_\gamma$ correlates well with $\log L_{\rm BLR}$.

In 2014, Ghisellini et al. complied a large sample of γ-ray detected sources with measured broad emission lines, and found a correlation between jet power as measured through the γ-ray luminosity, and accretion luminosity as measured by the broad emission lines, and that the jet power dominate over the disk luminosity.

Since there is a correlation between luminosity and redshift, then, even if there is no correlation exists in intrinsic luminosity-luminosity, a correlation still present on observed luminosity-luminosity (Mücke et al 1997). Feigelson and Berg (1983) obtained the correlations on mutual bands, and came to another conclusion that if there is no correlation between the luminosity-luminosity, nor is it in the flux-flux densities. Many works have been done to study the relationship between the γ-ray emission and other monochromatic emission of AGNs (Stecker et al. 1993; Padovani et al. 1993; Salamon and Stecker 1994; Fan et al. 1999; 2009; 2016). Some of the monochromatic emissions in blazars are strongly beamed. When the jet direction is close to the line of sight at rest frame, the luminosity will be enhanced by the beaming effect, which presents as a beaming factor (or a Doppler factor). Therefore the luminosity-luminosity correlations will also be influenced by the correlations between the luminosity and the beaming factor. In this sense, we should consider the effect of the beaming effect when we investigate the luminosity-luminosity correlations.

In the present paper, we compiled a large sample of 202 Fermi blazars with available redshift, radio, γ-ray, and broad-line emissions to study the correlation between jet and accretion

disk process. The paper is arranged as follows: in section 2, we will give the sample and some results; In section 3, some discussions and conclusions are given. The cosmological parameters $H_0 = 70\mathrm{kms^{-1}Mpc^{-1}}$, $\Omega_\mathrm{m} = 0.27$ and $\Omega_\Lambda = 0.73$ have been adopted in this work.

2. Samples and Results

2.1. Samples

In order to investigate the connection between the accretion process and jet, we collected the broad-line data for Fermi blazars from the literatures (Celotti et al. 1997; Cao and Jiang 1999; Sbarrato et al. 2012; Shaw et al. 2012; Xie et al. 2012; Xiong and Zhang 2014; Xue et al. 2016), and the radio and γ-ray data from Fan et al. (2016). **The total broad-line luminosity can be calculated by the total observed luminosities from all broad lines (Celotti et al. 1997), for some original data with flux density but no luminosity of broad-line emission, the broad-line flux density (f_{BLR}) are converted into luminosity (L_{BLR}): $L_{BLR} = 4\pi\nu d_L^2 f_{BLR}$, considering K-correction for broad-line flux density: $L_{BLR} = (4\pi\nu d_L^2 f_{BLR})/(1+z)$, where ν is the frequency, d_L is the luminosity distance, z is the redshift.** Therefore, we obtained a sample of 202 blazars with available monochromatic radio, γ-ray emissions and broad-line data, and listed them in Table 1. In Table 1, col. 1 gives the name of the source; col. 2 the redshift; col. 3 the classification,

F stands for FSRQs, B for BL Lacs, U for unclassified sources; FL stands for LSP-FSRQs, FI for ISP-FSRQs, IB for ISP-BLs, LB for LSP-BLs, HB for HSP-BLs, UI for ISP-unclassified sources, UL for LSP-unclassified sources; col. 4 the logarithm of radio luminosity ($\log L_\mathrm{R}$) in units of erg/s; col. 5 the uncertainty for $\log L_\mathrm{R}$; col. 6 the logarithm of the γ-ray luminosity ($\log L_\gamma$) in units of erg/s; col. 7 the uncertainty for $\log L_\gamma$; col. 8 the references for data in col. 4 - col. 7; col. 9 the logarithm of the broad line luminosity ($\log L_\mathrm{BLR}$) in units of erg/s; col. 10 references for col. 9, C97: Celotti et al.(1997), C99: Cao et al.(1999), S12: Sbarrato et al.(2012), X12: Xie et al.(2012), X14: Xiong et al.(2014), X16: Xue et al.(2016); col. 11 Doppler factor, δ; col. 12 references for Doppler factor, F09: Fan et al. (2009), H09: Hovatta et al. (2000), LV99: Lähteenimäki & Valtaoja (1999), L17: Liodakis et al. (2017), S10: Savolainen et al. (2010).

For the 202 blazars, 165 are FSRQs, 35 are BL Lacs, and 2 are unclassified blazars. The redshift (z) is in a range from 0.031 to 3.104, the radio luminosity ($\log L_\mathrm{R}$) is from $40.18(erg/s)$ to $44.71(erg/s)$, γ-ray luminosity ($\log L_\gamma$) is from $43.39(erg/s)$ to $48.01(erg/s)$, and the broad-line luminosity ($\log L_\mathrm{BLR}$) is from $41.70(erg/s)$ to $46.65(erg/s)$. We also obtained Doppler factors for 66 sources from the papers by Fan et al. (2009), Hovatta et al. (2009), Lahteenimaki and Valtaoja (1999), Liodakis et al. (2017), and Savolainen et al. (2010).

2.2. Results

For the relevant data in Table1, a linear least regression is applied to the luminosity-luminosity correlation, following results are obtained

$$\log L_\gamma = (0.79 \pm 0.05)\log L_{BLR} + (11.21 \pm 2.30)$$

with a correlation coefficient $r = 0.73$ and a chance probability $p = 2.43 \times 10^{-35}$, and

$$\log L_R = (0.78 \pm 0.05)\log L_{BLR} + (8.57 \pm 2.10)$$

with $r = 0.76$ and $p = 4.52 \times 10^{-39}$ for the 202 blazars.

For the subclasses, we have

$$\log L_\gamma = (0.72 \pm 0.08)\log L_{BLR} + (14.28 \pm 3.54)$$

with $r = 0.58$ and $p = 4.25 \times 10^{-16}$, and

$$\log L_R = (0.79 \pm 0.07)\log L_{BLR} + (8.33 \pm 3.02)$$

with $r = 0.67$ and $p = 4.39 \times 10^{-23}$ for the 165 FSRQs; and

$$\log L_\gamma = (1.07 \pm 0.12)\log L_{BLR} - (1.23 \pm 5.10)$$

with $r = 0.84$ and $p = 9.04 \times 10^{-11}$, and

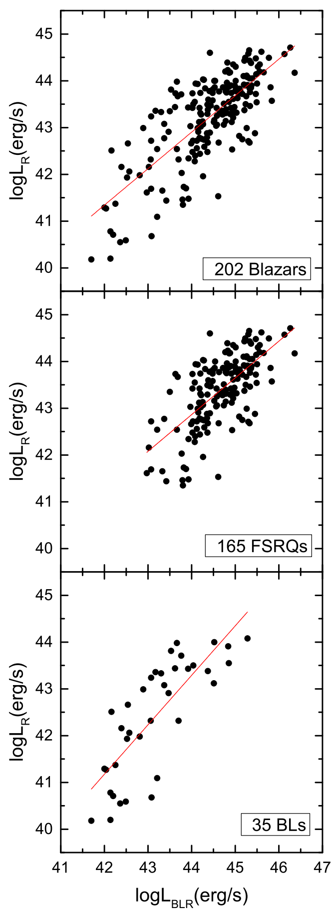
$$\log L_R = (1.06 \pm 0.14)\log L_{BLR} - (3.25 \pm 5.91)$$

with $r = 0.79$ and $p = 4.51 \times 10^{-9}$ for the 35 BL Lacs. They are all shown Fig.1 and Fig.2.

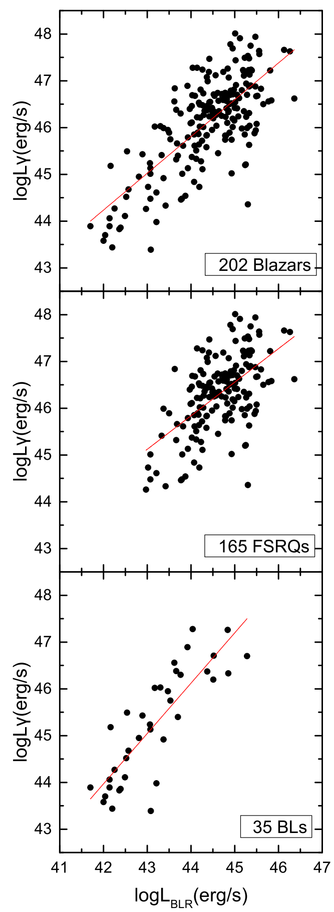
3. Discussions and Conclusions

In the theoretical models of jet formation, if the squared magnetic field is proportional to the accretion rate, a correlation between jet and accretion process is expected (Ghisellini et al. 2014), the power converted into the kinetic power of jet is produced from a spinning black hole which can release its rotational energy (Blandford and Znajek 1977), or produced from accretion process and disc (Blandford and Payne 1982).

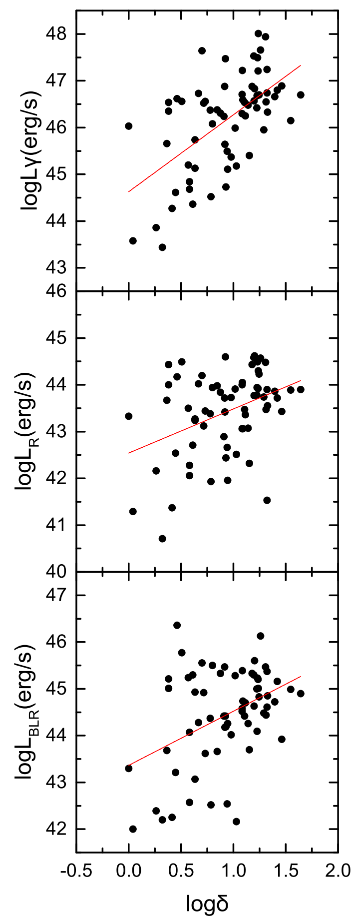
The broad-line region is photoionized by radiation from the disc, so the broad-line emission can be taken as a proxy of the accretion power of the source (Celotti et al. 1997), and can be expressed as $L_{\rm disk} = L_{\rm BLR}/\phi$, where $\phi \sim 0.1$ (Ghisellini et al. 2014). For a simple one-zone



(a) Fig.1: Plot of radio luminosity against emission line luminosity. From the top to the bottom is for 202 Blazars, 165 FSRQs and 35 BL Lacs.



(b) Fig.2: Plot of γ-ray luminosity against emission line luminosity. From the top to the bottom is for 202 Blazars, 165 FSRQs and 35 BL Lacs.



(c) Fig.3: Correlation between monochromatic luminosity (logL) and Doppler factor ($\log\delta$). From the top to the bottom is for radio, γ-ray and broad-line luminosity against Doppler factor.

leptonic model, the power that the jet spent in producing the non-thermal radiation is $P_{\rm rad} = 2f\frac{L_{\rm jet}^{\rm bol}}{\Gamma^2}$, where $L_{\rm jet}^{\rm bol}$ is bolometric jet luminosity, Γ is the bulk Lorentz factor of the outflowing plasma, the factor 2 accounts for two jets, and f is a factor of order unity. The power in radiation $P_{\rm rad}$ is believed to be about 10% of the jet power $P_{\rm jet}$, namely $P_{\rm jet} = 10P_{\rm rad}$ (see Ghisellini et al. 2014 for detail). So, we can use the bolometric jet luminosity as the proxy of the jet power and the broad emission line luminosity as the proxy of the accretion power.

Based on the detections by EGRET and Fermi/LAT, a series of studies have shown that there is a strong correlation between the γ-ray and radio emission (Dondi and Ghisellini 1995; Fan et al. 1998; Huang et al. 1999; Cheng et al. 2000; Abdo et al. 2009; Giroletti et al. 2010; Nieppola et al. 2011; Fan et al. 2016; Fallah et al. 2017). Those correlations suggest that the γ-ray emission has a beaming effect. We also found that the γ-ray luminosity and other monochromatic luminosities are strongly correlated with Doppler factor (Fan et al. 2017). The beaming factor (Doppler factor) is an important parameter for blazars, but it is difficult to determine. Doppler factors can be obtained from a synchrotron self-Compton mechanism (Ghisellini et al. 1993), from the radio variability (Lahteennimaki and Valtaoja 1999; Hovatta et al. 2009; Savolainen et al. 2010; Fan et al. 2009; Liodakis et al.2017), or by model fitting the SED of the sources (Ghisellini et al. 1998; Zhang et al. 2012, and references therein).

People think that the broad-line emission is taken as a good proxy for accretion disc. However, the radio emission is believed from the beamed jet, and it is also found that the γ-ray dominates the bolometric luminosity in Feremi blazars (Ghisellini et al. 2014). In this sense, the radio and γ-ray emission are good proxies for the jet emission while the broad-line emission is a good proxy for accretion process. The correlation between radio and broad-line emission was studied in some literatures. Many authors think that the correlation between the beamed emission and the broad-line emission is due to the close link between the relativistic jet and accretion disk (Celotti et al. 1997; Cao and Jiang 1999; Sbarrato et al. 2012; Xiong and Zhang 2014). Cao and Jiang (1999) found a correlation between radio and broad-line flux densities for 198 radio-loud quasars. Sbarrato et al. (2012) obtained a strong correlation between the γ-ray and broad-line luminosity. Fan (2000) also investigated such a relationship using the EGRET data and broad-line emission.

In our present work, we compiled a large sample with Fermi/LAT detections. Our results show a close correlation for $\log L_\gamma$-$\log L_{\rm BLR}$ with a coefficient $r = 0.73$ and a chance probability $p = 2.43 \times 10^{-35}$, and also a close correlation for $\log L_{\rm R}$-$\log L_{\rm BLR}$ with $r = 0.76$ and $p = 4.52 \times 10^{-39}$ for the whole sample. Our result is consistent with those by Sbarrato et al. (2012), Ghisellini et al (2014),and Chen (2018) for the γ-ray and broad-line emissions. However, the sample from Cao and Jiang (1999) was restricted to the radio flux at $5GHz$ and the total broad-line flux.

3.1. Redshift Effect

Redshift effect is an important factor influencing the luminosity-luminosity correlation. Considering the cross-correlation in luminosity-luminosity, it is necessary to remove redshift effect. It can be done using a formula: $r_{ij,z} = \frac{r_{ij}-r_{iz}r_{jz}}{\sqrt{(1-r_{iz}^2)(1-r_{jz}^2)}}$, here, r_{ij} is the correlation coefficient in luminosity-luminosity, r_{iz} (or r_{jz}) is the correlation coefficient between redshift and luminosity and $r_{ij,z}$ is the correlation coefficient in luminosity-luminosity after removing the redshift effect.

From our sample, we have got the correlation coefficients and listed them in Table2 for the whole and subclasses, the coefficients after removing the redshift effect are: $r_{L_\gamma L_{\rm B},z} = \frac{r_{L_{\rm R}L_{\rm B}}-r_{L_{\rm R}z}r_{L_{\rm B}z}}{\sqrt{(1-r_{L_{\rm R}z}^2)(1-r_{L_{\rm B}z}^2)}} = 0.28$ with $p = 5.77\times10^{-5}$ for logL$_\gamma$- logL$_{\rm BLR}$, and $r_{L_{\rm R}L_{\rm B},z} = 0.45$ with $p = 1.33\times10^{-10}$ for logL$_{\rm R}$-logL$_{\rm BLR}$ for the whole sample. For FSRQ subclass, we have $r_{L_\gamma L_{\rm B},z} = 0.25$ with $p = 1.5\times10^{-3}$ and $r_{L_{\rm R}L_{\rm B},z} = 0.49$ with $p = 3.36\times10^{-10}$ for the 165 FSRQs. For BL Lac subclass, we obtained $r_{L_\gamma L_{\rm B},z} = 0.55$ with $p = 1.1\times10^{-3}$ and $r_{L_{\rm R}L_{\rm B},z} = 0.47$ with $p = 5.9\times10^{-3}$ for the 35 BL Lacs.

So, after removing the redshift effect, we can see that there are still significant correlations in logL$_\gamma$-logL$_{\rm BLR}$ with $p = 5.77\times10^{-5}$ and in logL$_{\rm R}$-logL$_{\rm BLR}$ with $p = 1.33\times10^{-10}$ for the whole sample. The correlations also exist for the 165 FSRQs and the 35 BL Lacs.

3.2. Beaming Effect

Beaming effect is important for blazars, and included in the explanations of their observation properties. The emission in different energy bands is produced by different mechanisms with the radio emissions being from synchrotron emission while the high energetic γ-rays from a synchrotron-self Compton or external Compton. Therefore, the emission at different band has a different dependence on the Doppler factor. In the correlation analysis of γ-ray and other low energy bands, the γ-ray vs radio relation is found to be very strong in many literatures (Dondi & Ghisellini 1995; Fan et al. 1998, 2016, 2017; Giroletti, et al. 2010; Huang et al. 1999; Zhang, et al. 2000). The strong γ-ray and radio correlation is perhaps from the fact that γ-ray is from an SSC mechanism or that the γ-ray and radio emission are strongly beamed with the same Doppler factor (Fan et al. 2009). So, the Doppler factor estimated from the radio variability is adopted in the discussions of beaming effect in the γ-rays.

In this work, radio variability Doppler factors are available for 66 sources, and it is interesting to find that there is a correlation between the broad line luminosity and Doppler factor, see Fig.3. Therefore, it is necessary that the Doppler factor dependence of the monochromatic luminosity and broad-line luminosity should be considered when we investigate the luminosity correlations.

For the 66 sources, we have $r = 0.73$ and $p = 4.60\times10^{-12}$ for $\log L_\gamma$-$\log L_{BLR}$, $r = 0.75$ and $p = 3.89\times10^{-13}$ for $\log L_R$-$\log L_{BLR}$. The correlation coefficients are $r = 0.59(p = 2.01\times10^{-7})$, $0.39(p = 1.24\times10^{-3})$ and $0.42(p = 5.15\times10^{-4})$ for the correlations between γ-ray luminosity and Doppler factor, between the radio luminosity and Doppler factor, and between broad-line luminosity and Doppler factor. The observed radio and γ-ray luminosities are boosted in the jet, therefore they are correlated with Doppler factor. For the correlation between broad-line emission and Doppler factor, It is possible that some broad-line region enter the jet so that the emissions are boosted or the radiation from broad-line emission is produced by the plasma bubbles in relativistic motion, which show a hint that the broad-line emission clouds have relativistic motion in the direction of sight line, then there is an effect of jet on the broad-line clouds. So, it is not difficult to understand that broad-line vs Doppler factor correlation.

The correlation coefficients between the monochromatic luminosity and broad-line luminosity after removing the Doppler factors are: $r_{L_\gamma L_B,\delta} = 0.66$ with $p = 9.86\times10^{-8}$ for $\log L_\gamma$- $\log L_{BLR}$, and $r_{L_R L_B,\delta} = 0.70$ with $p = 1.12\times10^{-8}$ for $\log L_R$-$\log L_{BLR}$. We can see clearly that the correlation between the γ-ray luminosity (or radio luminosity) and broad-line luminosity exists even after the Doppler factor effect is removed.

Therefore, there is really a connection between the accretion process and jet even when the redshift and Doppler boosting effects are removed. In this sense, the connection between the accretion process and jet is robust.

3.3. Conclusions

In this work, we compiled a sample of 202 Fermi detected blazars with available radio and emission line data. Out of them, 66 sources have Doppler factors. The correlations between the γ-ray luminosity (radio luminosity) and broad-line luminosity are discussed for the whole sample and the subclasses. We also considered both redshift effect and beaming effect in our discussions. Following conclusions are reached:

1) Strong correlations between the γ-ray (and radio) luminosity and broad-line luminosity are obtained for the whole and the subclass (FSRQs and BL Lacs) samples. Those correlations exist for the whole sample and FSRQs/BL Lac sub-samples when redshift effect is removed.

2) The broad-line luminosity, the γ-ray, and the radio luminosities are all correlated with Doppler factor.

3) The correlation between the γ-ray (and radio) luminosity and broad-line luminosity exists after the beaming effect/(redshift effect) is removed.

4) There is a real connection between the accretion process and jet.

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Table 1:: Fermi blazars Sample

Source name	z	class	$\log L_R$	$\Delta\log L_R$	$\log L_\gamma$	$\Delta\log L_\gamma$	Ref	$\log L_{BLR}$	Ref	δ	Ref
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
J0017.6-0512	0.227	FI	41.46	0.02	44.48	0.05	F16	43.79	X14		
J0023.5+4454	1.062	FL	42.74	0.01	46.01	0.07	F16	44.28	X14		
J0024.4+0350	0.545	FL	41.35	0.02	45.01	0.09	F16	43.8	X14		
J0043.8+3425	0.966	FI	42.48	0.01	46.11	0.03	F16	44.02	X14		
J0046.7-8419	1.032	FL	43.29	0.04	45.89	0.11	F16	44.88	X14		
J0048.0+2236	1.161	FL	42.59	0.01	46.27	0.05	F16	44.29	X14		
J0050.4-0449	0.92	FL	42.88	0.01	45.83	0.07	F16	44.35	X14		
J0058.3+3315	1.369	FI	43.02	0.01	46.21	0.07	F16	44.21	X14		
J0105.1-2415	1.747	FL	43.38	0.02	46.71	0.06	F16	44.95	X14		
J0108.7+0134	2.099	FI	44.57	0.01	47.66	0.02	F16	46.13	X14	18.2	S10
J0137.0+4752	0.859	FL	43.47	0.01	46.55	0.02	F16	44.44	X14	20.5	S10
J0137.6-2430	0.838	FI	43.46	0.02	46.04	0.04	F16	45.34	X14		
J0208.6+3522	0.318	HB	40.2	0.05	43.89	0.13	F16	42.14	W02		
J0210.7-5101	1.003	UI	44.08	0.04	46.7	0.02	F16	45.28	Sb12		
J0217.1-0833	0.607	FL	42.72	0.01	45.01	0.1	F16	43.07	X14		
J0217.5+7349	2.367	FL	44.6	0.01	47.47	0.02	F16	44.42	C99	8.4	S10
J0237.9+2848	1.213	FL	44.05	0.01	47.22	0.01	F16	45.39	Sh12	12.2	L17
J0238.6+1636	0.94	LB	43.43	0.01	46.89	0.01	F16	43.92	X14	29	L17
J0245.4+2410	2.243	FI	43.76	0.04	47.13	0.06	F16	45.34	X14		
J0259.5+0746	0.893	FI	43.35	0.01	45.89	0.05	F16	43.5	X14		
J0303.7-6211	1.351	FL	44.18	0.04	46.5	0.04	F16	45.65	X14		
J0309.9-6057	1.48	FL	44.18	0.04	46.5	0.03	F16	44.88	X14		
J0325.5+2223	2.066	FL	43.86	0.01	47.22	0.04	F16	45.81	X14		
J0336.5+3210	1.259	FL	44.17	0.01	46.62	0.07	F16	46.36	C97	2.9	L17
J0339.5-0146	0.85	FL	43.78	0.01	46.42	0.02	F16	45	X14	16.7	L17
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Table 2:: Correlation Analysis Results

Class	N	r_{RB}	p_{RB}	r_{Rz}	p_{Rz}	r_{Bz}	p_{Bz}	$r_{RB,z}$	$p_{RB,z}$
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Blazars	202	0.76	4.52×10^{-39}	0.77	4.23×10^{-41}	0.73	1.06×10^{-34}	0.45	1.33×10^{-10}
FSRQs	165	0.67	4.39×10^{-23}	0.67	1.17×10^{-22}	0.55	1.12×10^{-14}	0.49	3.36×10^{-10}
BL	35	0.79	4.51×10^{-9}	0.81	1.95×10^{-9}	0.77	3.41×10^{-8}	0.47	0.59%
Class	N	$r_{\gamma B}$	$p_{\gamma B}$	$r_{\gamma z}$	$p_{\gamma z}$	r_{Bz}	p_{Bz}	$r_{\gamma B,z}$	$p_{\gamma B,z}$
Blazars	202	0.73	2.43×10^{-35}	0.88	~ 0	0.73	1.06×10^{-34}	0.28	5.77×10^{-5}
FSRQs	165	0.58	4.25×10^{-16}	0.84	4.93×10^{-46}	0.55	1.12×10^{-14}	0.25	0.15%
BL	35	0.84	9.04×10^{-11}	0.85	2.03×10^{-11}	0.77	3.41×10^{-8}	0.55	0.11%